Accounting for sustainable development over the long-run: lessons from Germany

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Abstract:

We construct long-run sustainability indicators based on changes in Comprehensive Wealth – which we refer to as Genuine Savings - for Germany over the period 1850-2000. We find that German sustainability indicators are positive for the most part, although they are negative during and after the two World Wars and also the Great Depression. We also test the relationship between these wealth changes and a number of measures of well-being over the long-run: changes in consumption as well as changes in average height and infant mortality rates. We find a positive relationship between GS and our well-being indicators over different time horizons, however the relationship breaks down during WWII. We also test if the Genuine Savings/Comprehensive Wealth framework is able to cope with massive disinvestment at the end of World War 2 due to war-related destructions and dismantlement. We find that negative rates of Genuine Savings were by and large avoided due to the accumulation of technology and growth-friendly institutions. We demonstrate the importance of broader measures of capital, including measures of technological progress, and its role in the process of economic development; and the limits of conventional measures of investment to understand why future German consumption did not collapse.

Keywords: Sustainability, economic development, German economic history, World War Two, Genuine Savings, investment, anthropometrics, consumption, well-being.

JEL codes: E01, E21, N10, O11, 044, Q01

1. Introduction

2016 marked the beginning of the United Nation's Sustainable Development (SD) Goals, replacing the Millennium Development Goals which ran until 2015. The United Nation's SD Goals, which are planned to run until 2030, cover 17 areas with the main objective of ending poverty in all its forms and promoting 'sustained, inclusive and sustainable economic growth'. How to measure the sustainability of economic growth and development is clearly an important question, therefore. In this paper, we use Germany's development over the period 1850 to 2000 to illustrate the link between SD, measured by Genuine Savings (GS), and future well-being, measured by per-capita consumption and anthropometric indicators. Our paper takes a new look at what factors contributed to changing living standards in Germany over a period of 150 years which included two major world wars, and the aftermath of these wars (especially World War Two). In particular, we are interested in how changes in comprehensive wealth can explain trends in future well-being over this period.

Genuine Savings (GS) is an indicator of sustainability based on the concept of wealth accounting (Hamilton & Hepburn 2014).[1] Ideally, GS measures how a country's total capital stock (physical, natural, social or institutional & human) changes year-on-year, since this stock of "comprehensive wealth" is seem as key to determining future well-being. Hamilton & Clemens (1999) and World Bank (2006, 2011) show trends in estimates of GS for most countries in the world and they outline how a negative GS indicator can be interpreted as a signal of unsustainability.[2] National level World Bank estimates of GS stretch back to the 1970s, and provide empirical evidence of the level of sustainable/unsustainable economic

[1] A similar approach is also adopted by the Arrow et al. (2012)/UNDP (2012, 2014), who also focus on measuring wealth and changes in wealth as a measure of sustainability.

[2] The World Bank has annually updated estimates and the most recent estimates covered 159, 152 and 131 countries in 2011, 2012, 2013: Data taken from http://data.worldbank.org/topic/environment [accessed 7 March 2016].

development throughout the world. At the global level, mean GS was 12.7 per cent of Gross National Income in 2014, however there was considerable variation in the data with values ranging from -27.9 to 36.9 per cent of Gross National Income.

Applying similar concepts to the longer historical record can inform policy makers about the sustainability paths adopted by countries, and about the factors determining the evolution of consumption over time. Recent scholarship has constructed long-run GS estimates for Britain, and shows that throughout its history Britain's GS rates have been positive on the whole (Greasley et al. 2014). A subsequent paper by Hanley et al. (2016) tested the theoretical properties of GS using a 3 country panel including Germany, finding that GS predicted changes in future consumption up to 50 years ahead. Both of these papers showed the key importance of including a measure of technological change – changes in TFP – in the GS indicator, to improve its predictive ability.

This paper utilises the checkered history of Germany as a case study, for which we construct and analyse detailed measures of German GS over the period 1850-2000. The case study approach taken in this paper offers a more thorough and systemic analysis of changes in comprehensive wealth and the consequences for German well-being than Hanley et al. (2016). By specifically focusing on the German experience, more insight can be obtained on the underlying drivers of Total Factor Productivity, and how the SD indicators relate to alternative well-being indicators to the consumption-based measure used in Hanley et al (2016). Over the period 1850 to 2000, Germany underwent unification and was a belligerent in two World Wars and also experienced the Great Depression. During this time period, German GS rates averaged 11.16 per cent of GDP, with a coefficient of variation of 0.84. German GS rates were consistently positive apart from during the two World Wars and the Great Depression.

Indeed, using German economic development as a case study offers insights into prospects for modern-day emerging economies, in terms of the impacts of (un)sustainability of current economic development. During its rapid phase of industrial industrialisation in the 20th century, Germany was more a follower than a leader in terms of economic progress. Its success was partly based on its role as a latecomer to the first Industrial Revolution, and an imitator of previous development successes in countries such as the UK. Germany was also a pioneer in the "second industrial revolution" in the field of chemistry and electricity, but its success was also based on exploitation of national resources and rising emissions of air and water pollutants. The lessons of German development are therefore relevant for modern developing countries, as Germany was a late developer in the nineteenth century and, unlike Britain, not the pioneering economy. Moreover, in terms of trends in comprehensive wealth[3], the combination of all stocks of capital, 1850's Germany shares similarities with many countries today. World Bank (2011, table 2.1) estimates of wealth for all countries in 2005 indicated that 'intangible capital' - human capital, social and institutional capital – comprises over 50 per cent of total wealth globally (in low-, lower middle-, upper middle- and high-income countries). In 1850, 69 per cent of German wealth was also comprised of 'intangible capital' and the remainder in produced and natural capital. How changes in the stocks that make up comprehensive wealth evolved is central to this study, because this metric reflects the basis for future income and consumption paths (Ferreira, Hamilton and Vincent, 2008; Greasley et al. 2014).[4]

[3] Refereed to as "total wealth" by the World Bank.
[4] In terms of income levels, at the start of our period of study Germany's GDP per capita was $GK 1428, it not only lagged behind contemporary leaders such as the UK ($GK 2330) and the USA ($GK1806), but it was considerably less well-off than developing countries in more recent years. For example, a number of world regions former USSR (GK$7877), Latin America ($GK 7027), East Asia ($GK 2267), West Asia ($GK 6931) and Africa ($1924) had higher GDP per capita levels in 2008 than Germany in 1850 (Bolt & Van Zanden 2013).

Furthermore, we use German disinvestment due to dismantlement and war-related destruction as a natural experiment in the context of sustainability.[5] This historical setting may serve as a basis to see how the theoretical model copes with these economic shocks, or whether the theoretical properties only hold in peacetime economic scenarios – this is extremely relevant for many developing countries today that continue to experience military conflicts. Indeed, for Germany we find that the main implications of the theory of SD is consistent with empirical facts for Germany over the long run if the value of technological progress is incorporated into our savings estimates. We find that the largest year-on-year falls in consumption per capita occurred during and immediately after the First and Second World Wars. However, the German economy was resilient enough to overcome these consumption shocks, regardless whether well-being is proxied by conventional, monetary metrics, or by alternative indicators such as average height and infant mortality. This resilience can be attributed to a range of accumulations in the comprehensive wealth stock which offset the loss of physical capital which has been well-described by economic historians.

Capital formation is the basis for any GS calculation and is a long-serving concept in growth accounting. The formation of capital has been discussed in various historical and more contemporary settings, such as the industrial revolution (see for example Rostow 1960).The study at hand makes use of the comprehensive wealth framework to add a novel facet to the existing literature on German economic growth in the long-run. Earlier approaches to explain Germany's rise focused on the role of the heavy industry (Tilly 1991); the interaction between the transportation sector and its demand for iron products (Fremdling 1977); the role of

[5] However, as noted by a reviewer, the world wars, especially the Second World War, should be treated with care in a discussion of causes and consequences of economic development. We do not claim that the world wars were perfectly exogenous to economic development as there are potentially endogenous links to natural resources (or the lack thereof), hyperinflation, capital flows and monetary policy and corresponding political, economic and societal tensions.

railways in fostering market integration (Fremdling 1975); the unique features of the banking sector and its role in industrial development (Tilly 1986, Guinnane 2002, Fohlin 2007). Broadberry (2004) analyses productivity and technology more broadly and highlights the role of the German service sector that enabled the German economy to overtake British productivity levels. As for the post-war period, discussion regarding German growth 'miracle' after WW2 include the role of the 'Marshall Plan' (Berger and Ritschl 1995), and whether post-war German growth should be interpreted as catch-up growth or convergence (Eichengreen and Ritschl 2009, Vonyo 2008, 2012). Factors that have been found to be helpful in explaining growth during this period include technological progress, including spill over effects through foreign direct investment, previous saving rates and physical capital accumulation, institutions, but also the undervalued German mark (see Bittner 2001 for a thorough discussion).

The economics of sustainable development has a strong focus on inter-temporal welfare, and the links between previous investment / saving rates and future returns in terms of consumption and well-being. The GS methodology allows a range of broader assets, such as human capital, social capital, natural resource use, pollution and technology accumulation to be accounted for in explaining long-run trends in well-being (Ferreira et al. 2008); this is where the central contribution of this study of German economic experiences post 1850 lies.

2. The economics of sustainable development

SD as a concept is a broad church with growing literatures in several academic disciplines (e.g. earth sciences, ecology, economics, and sociology: see Rogers et al. 2008). The focus of this study is the economic approach to SD. This paper draws on a well-established theoretical literature – see Hanley et al. (2015) for an extensive review.[6]

The Genuine Savings approach follows the weak sustainability paradigm, as it assumes a high degree of substitutability between the different assets which make up a country's stock of comprehensive wealth. Using the definition of SD from the Brundtland Report,[7] the weak approach to sustainability links future well-being with changes in this stock of wealth or capital (Pearce, 2002). The underlying logic is that future consumption can be seen as a return on past wealth accumulation. The GS approach to sustainability rests partly on the so-called Hartwick (1977) Rule , which shows how consumption can be constant over time if rents from natural resource extraction are re-invested in other forms of capital (i.e. man-made or human).[8] A macro level test of SD is to examine whether, year-on-year, an economy's per capita stock of comprehensive wealth is falling, rising, or remaining constant in value terms.[9] The intuition of Pearce and Atkinson (1993) was that countries with positive levels of GS would satisfy a requirement of weak sustainability, since by implication their total capital stocks would not be declining in value.

[6] The degree of substitutability between the different forms of capital which make up comprehensive wealth is an empirical question and it is one which is difficult to establish empirically (i.e. Markandya and Pedroso-Galinato (2007)).

[7] 'Sustainable Development is development that meets the needs of the present without compromising the ability of future generations to meet their own needs. It contains within it two key concepts: the concept of 'needs', in particular the essential needs of the world's poor, to which overriding priority should be given; and the idea of limitations imposed by the state of technology and social organisations on the environment's ability to meet present and future needs' (World Commission on Environment and Development, 1987, p.43).

[8] One of the attractions of GS is that it is grounded in the system of national accounts (SNA) framework and can be used to measure and compare countries in a consistent manner.

[9] Conceptually, Genuine Savings (GS) is an aggregate figure, representing the value of year-on-year changes in the capital stock of a country. Theoretically, these changes are most accurately measured when shadow prices are used, reflecting the marginal value product of each stock in terms of its contribution to welfare. This, in turn, is defined as the present value of aggregated utility over infinite time. Empirically, actual market prices and costs are used instead to proxy for shadow prices Moreover, prices for some environmental assets do not exist due to missing markets.

Most empirical tests of the predictive power of GS follow the empirical strategy of Ferreira and Vincent (2005) and Ferreira et al. (2005). The test is based on the representation of the long-run equilibrium relationship between GS and future well-being derived in Ferreira and Vincent (2005):

$$PVC_t = \beta_0 + \beta_1 S_t + \varepsilon \quad (1)$$

where PVC_t is the present value of changes in future consumption over some defined time period as evaluated at period t. The most stringent test from this specification relates to whether the β_1 coefficient on the sustainability indicator equals to 1 and whether the β_0 coefficient is zero, implying a one-for-one relationship between the SD indicator and the measure of future well-being. This has not been found in practice and less stringent tests are whether β_1 positive and greater than 0.[10] The approach taken in the present paper follows that of Greasley et al. (2014) and Hanley et al. (2016), who investigate the long-run relationship between future consumption and comprehensive investment in a series of countries. For the UK, data is analysed over the period 1760-2000, for Hanley et al. data for the USA, Germany and the UK are analysed over the period from 1870-2000. They found that the choice of time horizon and discount rate respectively, had the greatest effect on the estimated parameters than the alternative net savings measures used. Overall, they found that the inclusion of measures of technological change, which they proxied using the present value of changes in Total Factor Productivity (TFP) substantially improved the power of prediction of the estimated parameters, giving β_1 coefficients close to 1. This was interpreted by the authors as suggesting the GS was indeed a forward looking of consumption, even over periods 50 years ahead.

[10] See Hanley et al. (2015) for a review of the empirical literature

3. German GS estimates, 1850-2000

We largely follow the World Bank (2006, 2011) methodology for calculating GS to calculate a range of increasingly-comprehensive measures of year-on-year changes in total capital for Germany over time. We construct the following indicators:

1. Net investment = net fixed produced capital formation and overseas investment
2. Green investment = indicator (1) + Δ natural resource rents
3. Genuine Savings (GS) = indicator (2) + Δ human capital stocks
4. GS carbon = indicator (3) + carbon emissions
5. GreenTFP = indicator (2) + the present value of TFP growth
6. GSTFP = indicator (3) + the present value of TFP growth

The subsequent section outlines the historical trends in these data and a more comprehensive description of data and sources is provided in the accompanying data appendix.

3.1 Changes in produced and net overseas capital: net investment.

The net investment series we use comprises domestic net investment in produced capital (e.g. factories, machine tools, and transport links) and changes in foreign net capital stock, of which domestic investment is the major component. [11] Overall net investment varied around a 10 per

[11] Information on net investment are taken from Hoffmann, W.G., Grumbach, F., Hesse, H., 1965. Das Wachstum der deutschen Wirtschaft seit der Mitte des 19. Jahrhunderts. Springer-Verlag, Berlin, Heidelberg, New York., which still serves as the main source for German historical national account series. Hoffmann et al.'s (1965) investment series has been subject to criticism (see for example Fremdling and Stäglin 2003). We are aware of the shortcomings of these data and try to address them in the spirit of Vonyo (2012) and Scherner (2013). Given the lack of adequate alternative data, we follow the examples of Broadberry (2004) and Metz (2005) and use Hoffmann's series. We are confident that, despite Hoffmann et al.'s (1965) shortcomings, our data base serves as a valuable data basis for an empirical analysis. In Adjusted Net Savings frameworks accuracy of levels are certainly desirable, but more important are long-run trends for methodological reasons. A wide array of German historical national account statistics using Hoffmann et al.'s figures can be downloaded under www.gesis.org/histat.

cent of GDP during the mid-19th century. During the heyday of the German economy in the late 19th and early 20th century, net investment increased to approximately 15 per cent of GDP. Massive shocks occurred during the First World War, the inter-war years, and especially towards the end of the Second World War and the immediate post-war years when war destruction and dismantlement resulted in highly negative net saving rates.[12] German net investment was generally positive during the Nazi era, resulting in capital accumulation, especially in the heavy industries (Kirner, 1968; Vonyó, 2012). During the years of the "economic miracle", net savings rate were on an all-time high, ranging between 15 per cent and 20 per cent. Until the mid-1970s net savings rates subsequently declined to a level under 10 per cent and remained there for most of the period between 1975 and 2000 (Figure 1).

3.2 Natural capital

Natural capital consists of all "gifts of nature", including renewable and non-renewable resources, agricultural land, ecosystems and biodiversity (Barbier, 2011). Unfortunately, it was only possible to include a sub-set of these assets due to a lack of data, including a lack of a historical time series for non-market environmental resources. Changes in the natural capital stock are calculated from data on physical changes in certain stocks (e.g. due to depletion, for non-renewables) and the per-unit rental values of these changes. Renewable sources include forestry and coastal fisheries. In terms of forestry, the only noteworthy changes to the German forest stock seem to occur due to changes in territory. Given the nature and size of these

[12] Our statistical sources do not allow us to unambiguously differentiate between losses in capital due to destruction and dismantlement. The latter includes cash payments, but also in kind payments, such as machinery, manufacturing plants and part of the infrastructure. See Guinnane (2015) on details on German debt, reparations and the 1953 London Agreement on German External Debt. Also, there were plans to destroy the German armament industry. The combined effect on German capital stock was estimated by Krengel (1958), whose data we use below.

changes, we have not included changes in forestry stock in our metric. In the non-renewable sector, the most important commodities for Germany are brown and hard coal. Data on natural gas and crude oil depletion, iron ore, copper ore, zinc ore, lead ore, silver ore, tin ore, and nickel ore extraction are also included, but contribute only small shares to the overall figure on resource depletion. Costs of production have been subtracted from gross revenues using wages and employment figures in order to estimate the economic rent per unit of resource extracted. Figure 1 illustrates the net-contribution (gross revenues minus average extraction costs) of non-renewable resource depletion.

3.3 Changes in the stock of human capital

The stock of human capital is an important component of comprehensive wealth (World Bank 2011). There are a number of ways of calculating stocks of human capital and therefore deriving changes in the stock for the purpose of constructing GS. World Bank (2006, 2011) calculates human capital as a residual from total wealth, whilst Arrow et al. (2012) calculate human capital using Mincer equations, elsewhere McLaughlin et al. (2014) calculate stocks of human capital using the discounted lifetime earnings. Here we follow Hamilton and Clemens (1999, p.334, 336) who argue that investment in human capital can be proxied using education spending.[13] Figure 1 indicates that schooling expenditure in Germany, including investment in primary, secondary, and tertiary education, generally increased from under 1 per cent of GDP in the mid-19th century to 6.2 per cent in 1974. In the nineteenth century Prussia was in fact a leader in the provision of publicly funded education (Lindert, 2004). Significant slumps occurred during the 1920s, the Second World War and the post-war years. Slumps during the

[13] This method has limitations as it assumes that schooling equates to human capital development and it excludes on the job training, apprenticeships and other informal forms of human capital development

1920s and the war years are the result of disproportionate inflation of GDP relative to absolute education expenditure and a disproportionate economic upswing, respectively. Low human capital investment rate in the late 1940s are the result of generally low education expenditures combined with economic recovery. In terms of capturing information on public expenditure on schooling, we believe that our data series reflects this better than data provided by the World Bank database as this assumes education expenditure to be at a constant 4.3 per cent of GDP, whereas we utilise more accurate estimates provided by Diebolt (1997, 2000).

3.4 Carbon costs caused by pollution

In a further step, environmental costs due to pollution are included in changes to comprehensive wealth, based on the idea that emissions of greenhouse gases deplete the global assimilative capacity for such emissions, and thus constitute a negative investment flow which should be priced according to estimates of marginal damage costs per tonne of emission (e.g. Pezzey and Burke 2014, Kunnas et al. 2014). Over most of the period between 1850 and 2000, trends in German CO2 emissions correspond with overall economic activity, with increases before the end of the Second World War, brief interruptions in the 1920s and 1930s, a deep slump in the mid- and late-1940s, followed by a steep increase until the mid-1970s when absolute CO2 emissions started to decline. We use prices from Tol (2012) and discount the 2000 price, DM 37.96, in accordance with the growth rate of future prices (e.g. 1.99 per cent per annum). Expressed as a percentage of GDP, the value of carbon yields a small negative cost. Given the low value of carbon emissions relative to GDP, we do not anticipate that the inclusion of carbon in GS will affect our results dramatically.[14]

[14] See Kunnas et al. (2014) for a more comprehensive treatment of the issue of carbon pricing.

3.5 Changes in the value of exogenous technological progress (TFP)

One of the important drivers of modern economic growth is Total Factor Productivity or the 'Solow Residual'. However, the World Bank (2006, 2011) does not incorporate estimates of technological change or TFP in their adjusted net savings metrics. The importance of incorporating measures of technological change in sustainability indicators is illustrated by Weitzman (1997). TFP growth implies that even if capital stocks remain constant over time, potential output will increase due to efficiency gains. The significance of including a measure of technological change is further underscored in the Ferreira & Vincent (2005) test of GS's predictive power. They attributed the poor performance of GS at explaining changes in future consumption in OECD countries to the fact that TFP is attributed as being a driver of economic growth in OECD countries compared with factor accumulation in developing countries. As Pezzey et al (2006) note, the correct measure for technological progress which one includes in GS adjustments should be exogenous technological progress, which they refer to as a "value of time passing".

Therefore, we have incorporated the effects of exogenous technological progress in our measure of GS by including the present value of TFP growth. We calculate TFP assuming a standard Cobb-Douglas production function with capital and labour measured in manhours.

$$Y = AL^{(1-\alpha)}K^{\alpha}$$

where A denotes TFP which is estimated as a residual from this calculation, with α=0.37. We have estimated trend TFP growth using sources outlined in the appendix, and follow Pezzey et al. (2006) in that we use this to estimate the present value of the changes in GDP over the coming 20 year period in any accounting period to proxy the "value of time" or value of exogenous technological progress. The mean TFP growth rate of our series is 1.57 per cent (figure 2) and, in line with Weitzman (1997), we find that incorporating technological progress can make a sizeable adjustment to our indicators with the present value of TFP averaging 31.39 percent of GDP over the period 1851-2000.

For our purposes it would perhaps be ideal to measure TFP by incorporating human capital developments in the production function. This is the direction that recent theoretical and empirical research has taken when estimating TFP growth, such as Baier et al. (2004) and Manelli and Seshadri (2014). Particularly, Baier et al. (2004) find that incorporating a measure of human capital reduces the size of the residual but the resulting TFP growth rate is still sizeable. In the case of Germany, Baier et al. (2004), after incorporating human capital estimates, still find TFP growth of 1 per cent per annum. Moreover, Manelli and Seshadri (2014) argue that better measurements of human capital *quantity* and *quality* can further reduce TFP growth rates. For our purposes an alternative to our measure of TFP would be to incorporate data on human capital stocks, e.g. decadal from Baier et al. (2014) or Morrison and Murtin (2009), instead of labour per manhour.[15] Table 1 compares the TFP growth rates incorporating the data on human capital (with α=0.37) and our own calculations as well as the corresponding effect on the calculation of the net present value of TFP. The average TFP growth rate from Baier et al. is 61 per cent of our estimates of TFP using man hours and the TFP growth rate incorporating data from Morrison & Murtin (2009) is 87 per cent of the TFP growth rate calculated using man hours.

However, for the purposes of estimating changes in capital stocks, choosing to incorporate estimates of human capital stocks in our measure of TFP means we must also include better

[15] Baier et al. (2014) estimate decadal human capital stocks using data on years of schooling and mincer equations with constant coefficients for the returns to education and experience. Using the same underlying data as Baier et al. (2004), Morrison and Murtin (2009) have also estimated human capital stocks with calculated stocks reported as average years of schooling of the population at decadal intervals.

measures of the *changes* in the stock of human capital to the genuine savings estimates above. Data limitations prevent us from doing so, and reducing the size of the Solow residual without having equivalent improvements in changes in the stock of human capital would lead to mis-measurements of changes in the stock of human capital. We therefore opt to incorporate an unadjusted TFP series in our estimates, however in the results presented below we illustrate the effect of TFP appended to Green investment to avoid the possibility of double counting as education expenditure is already included in GS as a proxy for changes in human capital.

Moreover, the 'Solow Residual' encompasses factors in addition to technological progress which are unaccounted for in the production process, such as changes in institutions and social capital. Institutional change is an attractive explanation for the odd combination of highly negative investment between 1944 and 1948 and high growth in future consumption, since the Nazi regime was replaced by a more democratic political process after 1945 which paved the foundations for a functioning market economy, stabilizing the economy at large.

3.6 Well-being indicators over time

The underlying theory of SD indicators posits a link between Genuine Savings and future well-being/utility. In the theoretical work and in empirical tests, this is typically taken as implying a relationship between GS and the present value of future changes in consumption. We have collected data on private consumption per capita over the period 1850 to 2009, and this is used to measure changes in future well-being.[16] Limited as it may be, this reflects the economic outcomes for a population in constant monetary units. To implement the hypotheses tests set out earlier derived from Ferreira et al. (2008), the present value of the change in future

[16] This ignores the value of changes in the value of leisure time over the period, and other elements of full consumption.

consumption was calculated over four time horizons (30, 50, and 100 years ahead) using a 1.95 per cent discount rate (the average real interest rate in Germany from 1850-2010).[17] Figure 3 illustrates the present value of changes in consumption per capita over three different time horizons are presented.

An interesting facet evident in the underlying consumption data is that from 1850-2009 there is a year-on-year decrease in consumption in a total of 55 years, 36.66 percent of the data. However, when we calculate the present value of changes in consumption over the various time horizons (30, 50, and 100 years), we get much a lower number of negative values for the 30 year horizon, and none for the 50 and 100 year time horizons. Given Germany's eventful history – two World Wars interspersed with the Great Depression caused significant scars both from an social and economic point of view – a key question is why these drastic events did not result in a substantial decrease in future consumption. We only find two negative values over the 30 year horizon (1914 and 1915) and none for 50 or 100 horizons. Thus, despite collapses in our conventional measures of GS (1-4 above) in 1919, 1931-32 and 1945-1948, and although there are some year-on-year falls in consumption, we do not find similar drops in the present value of future changes in consumption. Why did German consumption not collapse and what factors other than conventional investment measures account for this? We believe that this may be explained by considering broader measures of capital which take into account changes in social and institutional capital.

[17] From a theoretical perspective, we should use flexible discount rates since investment, planning horizons, risk and opportunity costs may have varied over time. Ideally, we would have discount rates for every single year, and for every year we should have non-constant discount rate pertaining to different planning horizons (see Gollier 2013 for a thorough discussion). However, due to the lack of reliable and meaningful discount rate for Germany over the long-run we decided to follow the lead of pioneer studies (see Greasley et al. 2014, Hanley et al. 2015, Hanley et al. 2016).

Moreover, the theory underlying the properties of GS as a SD indicator relates the evolution of comprehensive wealth to future consumption paths. However, it has been argued that such conventional monetary-oriented welfare measures may be inaccurate when substantial shares of economic activity, such as subsistence farming or illicit markets are not included in official statistics. Alternative metrics may help to address this shortcoming and help to assess the wider implications of a country's long-term savings and investment strategy. We use infant mortality rate (IMR) and average male height to gain a fresh view on the impact of investment on future well-being in the long run. These metrics are frequently used as output-oriented proxies for living standards, reflecting the disease environment, nutritional standards and medical technology available (Baten and Blum, 2013; Gnegne, 2009). IMR is a non-monetary measure that reflects health standards but also informs about the health and education of women and poverty levels (figure 4). Average height can be interpreted as net-nutrition; this is gross nutritional intake less energy requirements to deal with diseases, physical labour, quality of housing, etc (figure 5).[18]

4. Testing the empirical relationship between Genuine Savings and future well-being

Figures 6a and 6b show the results of our calculations of GS for Germany and table 2 outlines decadal averages of all components outlined in section 3. Using the empirical strategy outlined in section 2, we have tested the relationship between increasingly comprehensive indicators of wealth changes and the present value of changes in future consumption. As noted in section 2, this is based on a theoretical relationship between changes in capital in the accounting period and future changes in well-being. In the strong version of the theory, we should find $\beta_1 = 1$ and

[18] There is a rich literature in this field, for example see: (Baten and Blum, 2012; Baten and Blum, 2013; Floud et al., 2011; Fogel et al., 1982; Komlos and Baten, 2004; Steckel, 1995).

$\beta_0 = 0$, since in the absence of positive net investment the future change in consumption is expected to be zero. A weaker test of the theory is to examine whether $\beta_1 > 0$.

Corresponding numerical results over three different time horizons are shown in table 3. Here β_0, β_1, the results of a series of Augmented Dickey-Fuller (ADF) tests, and several F-tests are shown. We use the ADF test to investigate whether the consumption and comprehensive investment series are cointegrated in order to assess a potential long-term relationship. F-tests are applied to test the hypotheses that $\beta_1 = 1$, and that $\beta_0 = 0$ and $\beta_1 = 1$ jointly. In our benchmark results our preferred discount rate is 1.95 per cent, which is based on real returns to German government bonds over the time period.[19]

We test the relationship between the present value of future changes in consumption (using a 1.95 per cent discount rate) and a set of investment metrics over 30, 50 and 100 year time horizons. In general, results indicate the existence of a positive relationship ($\beta_1 > 0$) between current investment and future well-being measured as private consumption. However, depending on the time horizon and investment indicator, the coefficient indicating the magnitude of this relationship varies considerably. The majority of tests indicate that $\beta_1 > 1$ and these coefficients tend to be larger for longer time spans, although for the 50 year horizon there is a break down in the relationship. We also test the hypothesis that $\beta_1 > 0$ and $\rightarrow 1$ as the investment metric includes more types of capital, again with the exception of the 50 year horizon. We find that this is the case for the 30 and 100 year horizons when we consider resource extraction, education expenditure, and costs of pollution as parts of net investment in comprehensive wealth.

[19] Appendix 1 includes a series of robustness tests which accounting for an alternative discount rates, a 3 % rate based on and also using a 3.0 per cent discount rate (the average rate of real GDP growth over the time period) and territorial/boundary changes, confirming the result presented below.

4.1 War shocks as a natural experiment and the role of TFP

Germany's experience during and immediately after the Second World War can be seen as a natural experiment that allows the assessment of the consequence of disinvestment due to war-related destruction and dismantlement in the GS framework.[20] These disinvestments are man-made consequences of political and military actions.

The theoretical models underlying GS, such as described in Hamilton and Withagen (2007), do not take into account shocks such as war-related destruction and dismantlement in Germany during and after WWII although there is a need to take shocks into account in empirical models (Perron 1989). Figure 7a illustrates the relationship between GS and present value of future changes in private consumption over a 50 year time horizon for the German case. A series of extreme values, referring to the years between 1944 through 1948, are located in the upper left of the scatterplot to illustrate this effect. Negative investment rates can be explained by capital being destroyed and damaged during the war years, whilst positive differences in future consumption are mainly driven by a catch-up growth and consumption in the post-war era. When the Ferreira et al. (2008) empirical strategy is applied to German data, the resulting estimated relationship is indicated by the dotted line. In this case, the existence of a small number of outliers reduces the value of the coefficient, systematically underestimating the empirical relationship between investment and discounted future consumption growth. If we were to exclude the war and post-war period, empirical tests might reflect a relationship between GS and utility more in line with the theory (solid line).[21]

[20] Conversely, the First World War was not as destructive as the Second World War (De Long and Eichengreen 1991, p.22-23); Germany's economy was severely affected during 1914-19, but did not experience man-made destructions comparable to those occurred during 1944-48. As a result, the inclusion of 1914-19 has little impact on our results. Furthermore the early years of the Second World War were seen as a boom to Germany as its capital stock grew significantly (Kirner 1968). However, the final years of the War, Germany's economy suffered from massive war-related destructions, followed by post-war dismantlement.

[21] Using a 3 % discount rate gives an identical relationship to that discussed above: see Appendix 1.

The conventional GS framework (table 3) has been designed as a tool to address gradual developments in investment and consumption; on its own it cannot account for the future sustainability of the German economy, as is indicated by the outlying observations which combine massive disinvestment and surprisingly high future consumption values. Consequently, the conventionally estimated relationship between investment and present value of future changes in consumption is mis-represented, which is illustrated by the rather flat regression line (dotted line).

As noted above, TFP incorporates all inputs not accounted for in the underlying production function, including social and institutional capital and, as was shown in section 3.5, when estimates of the human capital stock are incorporated into a measure of TFP the residual does not fall to zero. This suggests a role for other variables unaccounted for such as technological progress as well as social & institutional capital.

Germany (East & West) are widely considered to have undergone significant institutional change following the second world war, this is evident from the Polity IV database which shows Germany transitioning from a high level of autocratic regime to a high democratic regime following the end of the War (Marshall, Gurr and Jaggers 2014). Landmark institutional changes in the immediate post-war period include the trials of war criminals at Nuremburg (1945-6), followed by agreements to bolster German industry, Marshall Aid and Federal elections (1949) (Carr 1991). Authors have also highlighted the democratisation, military occupation and Marshall Aid programs ($200 per capita in 2001 prices) (Dobbins 2003). Whereas, the Eastern experience was significantly different, with authoritarianism and little external assistance, instead asset striping was more prevalent.

In terms of social capital, a number of authors argue that German social capabilities explain post-war recovery (Olson 1982, Dumke 1990, DeLong and Eichengreen 1991, Dobbins 2013).

Putnam (2000, p. 402) argues that creating/re-creating social capital can be eased by a palpable national crisis such as a war, depression or natural disaster. In the case of the US in the twentieth century, Putnam (2000, pp 268-271) highlights the role of World War II as a collective experience and by 'accentuating civic and social equality'. The post-WWII defeat in Germany can be considered such a palpable national crisis, particularly in that the country was under occupation.[22] De Long and Eichengreen (1991) also highlighted that out of all the European reconstructing nations, Germany, the country with the strongest US influence, was the most successful performer in the post-War period. Furthermore, Dobbins (2003) argues that a key feature in the reconstruction of the German economy, which contrasts strongly with more recent efforts in Somalia, Haiti and Afghanistan, was not that Germany was a highly developed economy returning to trend growth but rather that it had high levels of social capital; it was not divided ethnically, socio-economically or tribally. Thus, as these accounts highlight, the post-War period has multi-faceted institutional change both internally and externally which explain post-war economic growth and why GDP, and thus consumption, in Germany did not experience a collapse.

To investigate the role of intangible assets, such as social capital and institutions, we run two sets of regressions and show corresponding β1 coefficients. These regressions aim at showing a correlation between investment metrics and future changes in consumption without bearing the risk of distortion by the difficulty of finding a monetary metric for social capital and institutions. Results, shown in table 4, indicates that the monetized value of TFP is an important addition to conventional components of augmented saving and investment metrics.When technology (TFP) is incorporated, the value of β_1 drops for all time horizons. In

[22] Social capital was re-built in Germany as evident by rrecent estimates of social capital in Germany suggest relatively high levels, with Lee et al. (2011) ranking Germany just below the UK, at 14th out of 72 countries.

this case we also find that $\beta_1>0$ for the 30-year time horizons and $\beta_1>1$ for time horizons exceeding 30 years, and that this coefficient is closer to the size predicted by theory ($\beta_1 = 1$). The hypothesis that $\beta_1 = 1$ & $\beta_0 = 0$ jointly is rejected on the basis of this set of tests. Additionally, we apply a set of cointegration tests to assess a long-term relationship between aforementioned investment indicators and present value of future consumption at any given point in time.[23] This measure helps us to assess this relationship from a different angle. We find that in our preferred 1.95 per cent scenario both series are cointegrated over 100 years if conventional investment and GS metrics are considered, but not for shorter periods. This is in line with the prediction of the underlying theoretical models discussed in section 2 which assume an infinite time horizon

4.2 GS and alternative indicators of well-being

A large body of research suggests that monetary income metrics are insufficient to fully capture well-being, especially during the early stages of economic development. Differences in the size of the shadow economy, public goods and non-monetary market activities motivate the use of alternative, outcome-oriented welfare indicators (Schneider 2005; Steckel 1995).

Unfortunately, there is no defined theoretical relationship between alternative non-monetary indicators of well-being and GS that we can base hypothesis tests on. However, previous empirical studies have attempted to determine if in fact there is a correlation between

[23] As highlighted by a reviewer, the time series used in the cointegration analysis should be discussed in light of their 'stickiness'. While we consider nominal wages to be rather sticky, there is empirical evidence that real wages are quite volatile in Germany, especially during the mid-nineteenth century, the two world wars, and the interwar period, predominantly due to inflations rates (Kuczynski 1947). Similarly, recent research using alternative consumption metrics suggests that wellbeing during WW1 was seriously affected by the lack of consumption possibilities (Blum 2011; Cox 2013); similarly, the food crisis in Germany immediately after the end of WW2 constitutes a structural break in German consumption (Jürges 2013). Furthermore, disinvestment during the world wars suggests that investment during the period under observation is also not as sticky as economic intuition suggests. This holds even more for comprehensive indicators, such as ANS, since it is composed of monetary indicators, such as expenditure in education, which can be marginalised in times of inflation.

GS and non-monetary indicators of well-being. Gnégé (2009) looks at the correlation between GS and changes in both IMR and the Human Development Index (HDI) using data for 36 countries over the period 1971 to 2000. In general, Gnégé (2009) found a positive relationship between GS and future changes in IMR with coefficients ranging from 27.64 and 36.87 over 15 year time horizons. For HDI, coefficients ranged from 0.043 to 0.571 for 5 and 10 year horizons. Gnégé (2009) concluded that the results would be more consistent with theory if they could be tested over a longer time horizon.

We thus first compare GS with corresponding values of IMR and average male height. Figure 4 and Figure 5 illustrate how GS increases constantly prior to the Second World War, experiencing slumps during the First World War and economic crises in the 1920s and 1930s. After a substantial break with highly significant saving rates between 1944 and 1948 due to war-related effects, GS increased rapidly. Corresponding development in IMR and average height reflect this development to some extent only. IMR during the 19th century did not show a clear trend despite growing GS. Beginning in the early 20th century IMR fell rapidly, with a modest increase during the Second World War. After 1948, GS increased substantially while the velocity of IMR declines slowed down.

Similarly, average height does not follow a clear trend until the late 19th century. The series indicates rising average heights until 1914, when food shortages led to deteriorating living standards during First World War (Blum, 2011; Blum, 2013b). During the interwar period, economic turmoil and the Nazi government's autarchy policy put downwards pressure on nutritional and health standards in Germany (Baten and Wagner, 2003). The Second World War did not lead to decreasing heights, but hindered further improvements. Between 1945 and the 1960s German heights experienced substantial increases due to improvements in food quantities and quality, as well as medical advances and reduced physical work burden.

Interestingly, substantial increases in GS during the 1980s did not lead to increases in IMR and average height of the same magnitude. The reason for this apparent contradiction lies in the nature of the target variable which is supposed to reflect outcomes of previous investments. However, IMR cannot improve beyond zero, and average height is not likely to be outside a certain biological minimum and maximum. The measurement space in both anthropometric metrics has natural and biological limits, and approaching these limits corresponds with decreasing returns to utility, i.e. health and nutrition (Blum 2013a). Average height values reached towards the end of the height series indicate that a biological limitation is close; in fact Germans born in the late 1970s are not far off the average height values observed in the tallest of countries, such as the Netherlands (Baten and Blum 2012). On the other hand, investment does not face similar boundaries as it can – at least in theory – grow almost infinitely, since its value is determined not only by quantity but also but its price. Any analysis combining previous investments and future anthropometric outcomes needs to take this phenomenon into account.

Following Gnégé (2009), we assess the correlation between both future changes in infant mortality rates and average heights and GS in the long run using Germany as an example. We plot GS against the changes in average height over 30 years (hollow circles), obtaining a generally linear relationship between these two variables (figure 7b). However, the effect of WW2 prevents a coefficient to pick up the otherwise linear relationship between GS and changes in height; a dashed regression line indicates the slope of a (linear) regression coefficient if the war effect is not controlled for. When we use GS including the value of TFP, however, this war effect seems to be outweighed by the value of technology (solid circles). However, Germany's TFP grew substantially during the 1930s and early 1940s, adding value on the GS+TFP metric; therefore, the following increases in height over 30 years are disproportionately small because by this time Germany was among the tallest populations already and diminishing returns to consumption resulted in smaller increase in height compared with what the conventional GS framework implies. The result is a somewhat orthogonal-shaped distribution of observations, with GS+TFP having a beneficial effect on height growth for the period before the mid-1930s, and a negative relationship thereafter; a solid and a dotted regression line illustrate the idealised relationship between GS+TFP and changes in height before and after this reference point, respectively.

A similar problem occurs when using the infant mortality rate (IMR) to proxy improvements in the health status of the German population. Generally, the theoretical framework linking investment and future changes in consumption suggests a negative relationship between GS and IMR since positive GS rates are expected to reduce the IMR. Indeed, we do find such a negative correlation for the period before 1920 (figure 7c). Solid lines indicate the relationship between reduction in IMR over 30 years using GS (hollow circles) and GS + TFP (solid circles) as proxies for investment. For the period thereafter, however, we find a positive relationship between these variables (dashed regression lines). Again, the reason for the positive relationship – increasing investment coincides with lower reductions in IMR – is the nature of this metric. IMR has a natural lower limit of zero and Germany's IMR is on fairly low levels in the 1930s. Reductions on low IMR require more time and resources than on higher IMR levels due to diminishing returns to investment with respect to Germany's disease environment.

We calculate measures of changes of 5, 10, 20, 30 and 50 year time horizons, and have tested over shorter horizons (5 and 10) to correspond with the horizons tested by Gnégé (2009). We do not test the hypothesis that there is a one-to-one relationship between investment and resulting welfare as outlined above since these alternative welfare proxies are not considered by standard theoretical reasoning. Instead, our null hypothesis is that positive levels of (ln) GS per capita at time *t* should be associated with improving measures of IMR and height at some future period. Both anthropometric metrics are ordered by time of birth. While this procedure is straightforward in the case of IMR, the rationale to do this for average height is that the crucial period for the determination of final average height is the first three years in life. The results, presented in tables 7 and 8, are intuitive as the shorter the time horizon the less likely we are to find a strong correlation between changes in our well-being indicators and our measures of GS. What we do find though are that the size of the coefficients increase significantly the longer the time period considered, from 1.311 to 34.72 in the case of lnGS and 2.704 to 48.93 for the case of lnGSTFP thus emphasizing the importance of long-run analyses for capturing the full effect of comprehensive investment metrics on future well-being. With average heights we find that the shorter time horizons (5 and 10 years) perform very poorly. But as the time horizons increase we see stronger positive relationships between future changes in heights and lnGS. In the case of lnGSTFP we find an even stronger relationship with future changes in heights and also significant cointegrating relationships. However, in the case of IMR we do not find evidence of cointegrating relationships. In sum, although this methodology differs from the conventional strategy of capturing future changes in well-being, they do indicate that there is a positive correlation between lnGS and future changes in well-being, however it is defined.

5. Discussion and Conclusions

In this paper we have constructed long-run estimates of savings-based sustainability indicators for Germany over the period 1850 to 2000. We found that over this period, German GS rates were positive for the most part except for the two World Wars and the Great Depression. We also tested the predictive power of GS by constructing tests of the relationship between GS and the present value of future changes in consumption.

The results presented in table 3 and table 4 found that increasingly comprehensive indicators of sustainability were good predictors of future changes in well-being. For example, the β1 coefficients of our GSTFP metric (GS including TFP) ranged from 0.781-1.380, with theory predicting a value of 1. Our results were sensitive to both time-horizon and discount rate. In the German case, our results were also very sensitive to the effects of wars as these had dramatic effects on both investment and consumption. However, including the present value of changes in total factor productivity as a means of picking up changes in technology and social capital in the course and immediate aftermath of the war changes the relationship between net investment and future consumption, and helps us to understand the positive German consumption pattern despite the major physical destructions and dismantlement which occurred during and after the Second World War.

Another contribution of this paper was to analyse the relationship between GS and alternative measures of well-being, namely average heights and infant mortality. Generally, we found a positive correlation between future changes in both IMR and heights and our GS metrics. The framework developed by Ferreira et al. (2008) of a one-for-one relationship between increases in GS and well-being does not automatically transfer, as these anthropometric variables are different in nature. Our result suggest that on low levels of economic (and anthropometric) development, using these metrics as an alternative to conventional, monetary metrics can be a fruitful exercise; however, we do not find these metrics suited to assess the relationship between Genuine Savings and well-being on more advanced stages of development.

In conclusion, our paper shows that tracking changes in comprehensive wealth, including measures of social capital and technological change, can help develop a useful means of both thinking about causes of historical patterns of economic growth and well-being, but also of predicting future changes in well-being, at least when per-capita consumption is used as a well-being measure. Simply tracking changes in produced capital is inadequate for these purposes since changes in all of the assets on a which a country depends need to be ideally accounted for. Germany’s experiences over the period 1850-2000 show this clearly.

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Table 1 Estimates of TFP incorporating human capital versus Labour (man hours)

	TFP growth rate (%)	NPV TFP% of GDP
Baier et al. (2004)	0.97	18.06
Morrison & Murtin (2009)	1.37	26.72
Authors' calculations	1.57	31.39

Table 2: Decadal averages of Sustainability indicators (% of GDP)

	Net	Green	GS	GS carbon	GS + TFP	Green+ TFP
	%	%	%	%	%	%
1850s	8.25	7.88	8.60	8.59	23.76	24.10
1860s	10.26	9.78	10.66	10.64	26.49	24.95
1870s	11.79	11.06	12.13	12.10	28.44	27.17
1880s	10.89	10.06	11.47	11.43	33.65	28.66
1890s	13.29	12.14	13.73	13.67	37.99	32.41
1900s	13.96	12.41	14.38	14.27	42.01	37.07
1910s	13.64	11.57	13.65	13.50	59.29	45.23
1920s	9.69	8.29	9.90	9.74	54.72	49.02
1930s	7.04	5.85	8.73	8.57	62.99	53.83
1940s	***-9.51***	***-10.71***	***-8.60***	***-8.82***	47.13	45.00
1950s	16.92	13.80	16.60	16.23	70.12	66.69
1960s	17.11	15.70	19.55	19.22	57.63	57.89
1970s	10.92	10.17	15.86	15.54	45.87	42.93
1980s	8.08	7.52	12.65	12.34	41.00	35.15
1990s	6.51	6.47	10.73	10.49	36.61	31.85
1850-2000	9.90	8.78	11.33	11.16	44.60	40.18

Table 3: Estimated parameter values for alternative measures of investment when future wellbeing is measured by the PV of consumption per capita over 20-100 years horizons, 1.95 per cent / year discount rate

Dependent variable	Independent variable	β1	Standard error	β0	Standard error	β1=1	β0=0; & β1=1	ADF	R^2	Sample
PV Cons. 30	Net	1.636***	(0.253)	1,128***	(366.1)	6.30**	24.45***	-1.674	0.246	1850-1979
PV Cons. 50		0.063	(0.479)	3,099***	(500.4)	3.82*	22.48***	0.270	0	1850-1959
PV Cons. 100		3.356***	(0.233)	355.0**	(154.9)	101.97***	420.48***	-3.189**	0.781	1850-1909
PV Cons. 30	Green	1.596***	(0.272)	1,343***	(362.8)	4.81**	25.45***	-1.564	0.212	1850-1979
PV Cons. 50		-0.301	(0.501)	3,313***	(480.3)	6.73**	25.58***	1.167	0.003	1850-1959
PV Cons. 100		3.629***	(0.288)	366.8**	(174.8)	83.44***	361.19***	-2.909**	0.733	1850-1909
PV Cons. 30	GS	1.515***	(0.199)	1,016***	(342.1)	6.67**	22.77***	-1.695	0.311	1850-1979
PV Cons. 50		0.0774	(0.486)	3,088***	(512.3)	3.61*	21.89***	0.141	0	1850-1959
PV Cons. 100		3.279***	(0.226)	327.6**	(155.2)	101.77***	416.19***	-3.107**	0.784	1850-1909
PV Cons. 30	GScarbon	1.520***	(0.204)	1,037***	(343.9)	6.53**	22.94***	-1.686	0.303	1850-1979
PV Cons. 50		0.0217	(0.488)	3,126***	(510.6)	4.01**	22.25***	0.276	0	1850-1959
PV Cons. 100		3.298***	(0.229)	324.9**	(156.6)	100.63***	412.15***	-3.087**	0.781	1850-1909

Note: "PV Cons. N" refers to the present value of changes in future consumption over a N year horizon. In the columns β1=1 and β0=0 &β1=1 the results of a set of Wald-tests are reported which indicate whether aforementioned hypotheses in regard to size of β0 and β1 have to be rejected. Statistically significant coefficients suggest rejection. In the column labelled ADF results of a set of Augmented Dickey Fuller statistic which was used to perform the Engle-Granger (1987) two-step method to test for cointegration. Statistically significant values indicate a cointegrated relationship. The degree of augmentation is determined by the Hannan-Quinn Information Criteria. ***, **, and * indicate rejection of the null of non-stationary residuals at the 1%, 5%, and 10% level, respectively.

Table 4: Estimated parameter values for alternative measures of investment when future wellbeing is measured by the PV of consumption per capita over 20-100 years horizons, 1.95 per cent / year discount rate

Dependent variable	Independent variable	β1	Standard error	β0	Standard error	β1=1	β0=0; & β1=1	ADF	R^2	Sample
PV Cons. 30	GreenTFP	0.861***	(0.0573)	-660.9**	(294.4)	5.90**	24.07***	-2.398	0.639	1851-1979
PV Cons. 50		1.327***	(0.135)	-620.7	(478.1)	5.85**	3.54**	-2.449	0.474	1851-1959
PV Cons. 100		1.460***	(0.064)	145.1	(108.2)	51.66***	222.62***	-3.407**	0.901	1851-1909
PV Cons. 30	GSTFP	0.781***	(0.0523)	-551.5*	(290.2)	17.51***	39.87***	-2.173	0.637	1851-1979
PV Cons. 50		1.294***	(0.13)	-685.9	(478.5)	5.10**	2.78*	-2.432	0.48	1851-1959
PV Cons. 100		1.380***	(0.0593)	169.1	(105.2)	41.08***	191.55***	-3.393**	0.905	1851-1909

Table 7: Estimated parameter values for investment indicators and future changes in infant mortality rates

Dependent variable	Independent variable	β1	Standard error	β0	Standard error	R2	ADF	Sample
Δimr5	lnGS	1.311	(2.218)	-18.17	(15.47)	0.014	-4.070**	1850-1993
Δimr10		2.45	(2.906)	-36.83*	(20.09)	0.036	-2.678*	1850-1988
Δimr20		10.21***	(3.445)	-114.1***	(23.62)	0.203	-2.727*	1850-1978
Δimr30		19.39***	(3.903)	-197.4***	(26.5)	0.44	-1.585	1850-1968
Δimr50		34.72***	(8.023)	-335.2***	(53.3)	0.502	-1.573	1850-1948
Δimr100		28.94***	(7.863)	-420.0***	(48.78)	0.365	-1.618	1850-1898
Δimr5	lnGSTFP	2.704	(2.298)	-32.35*	(18.5)	0.011	-4.114***	1851-1993
Δimr10		3.789	(2.795)	-51.81**	(22.5)	0.014	-2.998**	1851-1988
Δimr20		12.64***	(3.041)	-145.9***	(24.45)	0.121	-3.576***	1851-1978
Δimr30		22.32***	(3.244)	-243.5***	(25.88)	0.283	-2.101	1851-1968
Δimr50		48.93***	(5.387)	-487.8***	(42.28)	0.429	-2.334	1851-1948
Δimr100		45.51***	(8.717)	-566.5***	(62.45)	0.372	-1.978	1851-1898

Table 8: Estimated parameter values for investment indicators and future changes in average male heights

Dependent variable	Independent variable	β1	Standard error	β0	Standard error	R2	ADF	Sample
Δheight5	lnGS	-0.15	(0.236)	1.867	(1.553)	0.004	-4.093 ***	1850-1974
Δheight 10		-0.00573	(0.281)	1.449	(1.848)	0	-3.466***	1850-1969
Δheight 20		0.313	(0.345)	0.565	(2.253)	0.009	-2.189	1850-1959
Δheight 30		0.667*	(0.362)	-0.34	(2.355)	0.036	-1.494	1850-1949
Δheight 50		1.571***	(0.377)	-3.271	(2.427)	0.186	-1.807	1850-1929
Δheight5	lnGSTFP	0.149	(0.179)	-0.3	(1.398)	0.006	-4.433***	1851-1974
Δheight 10		0.404*	(0.224)	-1.704	(1.741)	0.03	-3.814***	1851-1969
Δheight 20		1.048***	(0.257)	-5.408***	(1.984)	0.143	-3.050**	1851-1959
Δheight 30		1.552***	(0.262)	-7.825***	(2.01)	0.27	-2.434	1851-1949
Δheight 50		2.176***	(0.299)	-9.476***	(2.247)	0.408	--3.404**	1851-1929

Figure 1: German net investment, resource depletion and education expenditure as a percentage of GDP, 1850-2000

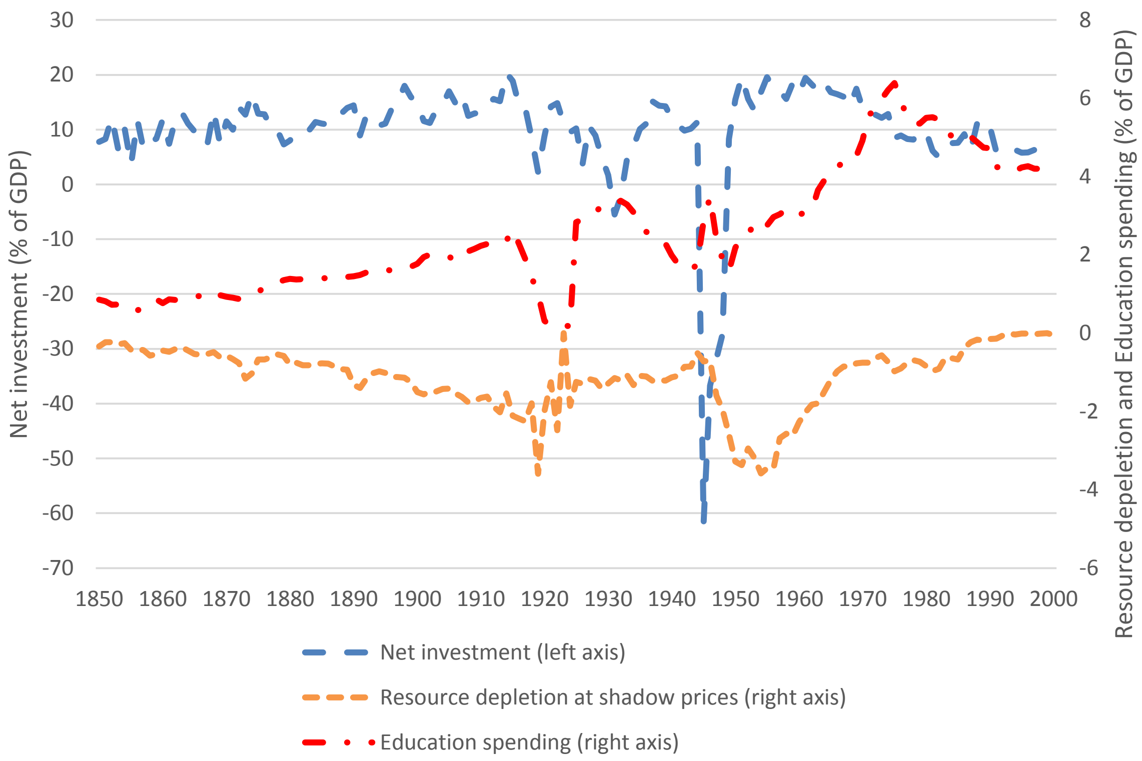
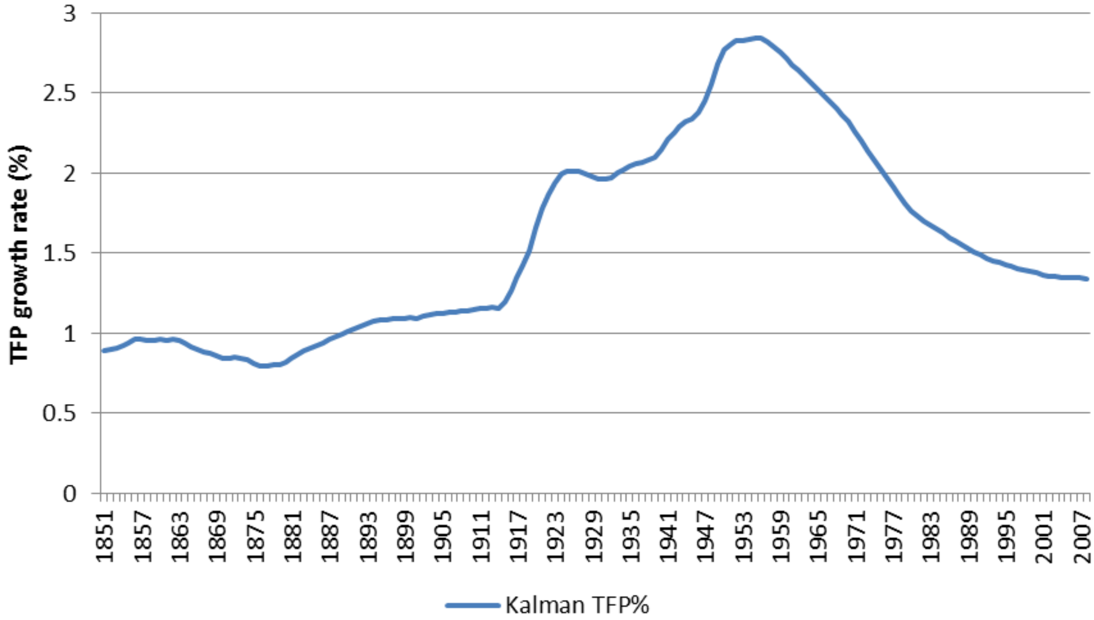


Figure 2: German trend TFP growth, 1851-2008



Note: Data on labour hours worked and real GDP is taken from Hoffman (1965) and Greasley and Madsen (2006). Information on capital stock for the period 1850 through 2000 is provided by Metz (2004). Missing values during and after the Second World War have been estimated on the basis of Krengel (1958). Factor shares used were from Greasley and Madsen (2006), labour share of 0.63 and a capital share of 0.37 based on average labour share of GDP from 1850-2008. A Kalman filter of the TFP growth rate was estimated, this was used to calculate the present value of TFP's contribution to GDP growth (in line with Pezzey et al. (2006)).

Figure 3: Present value future changes in consumption per capita, (1990 DM, 1.95% discount rate)

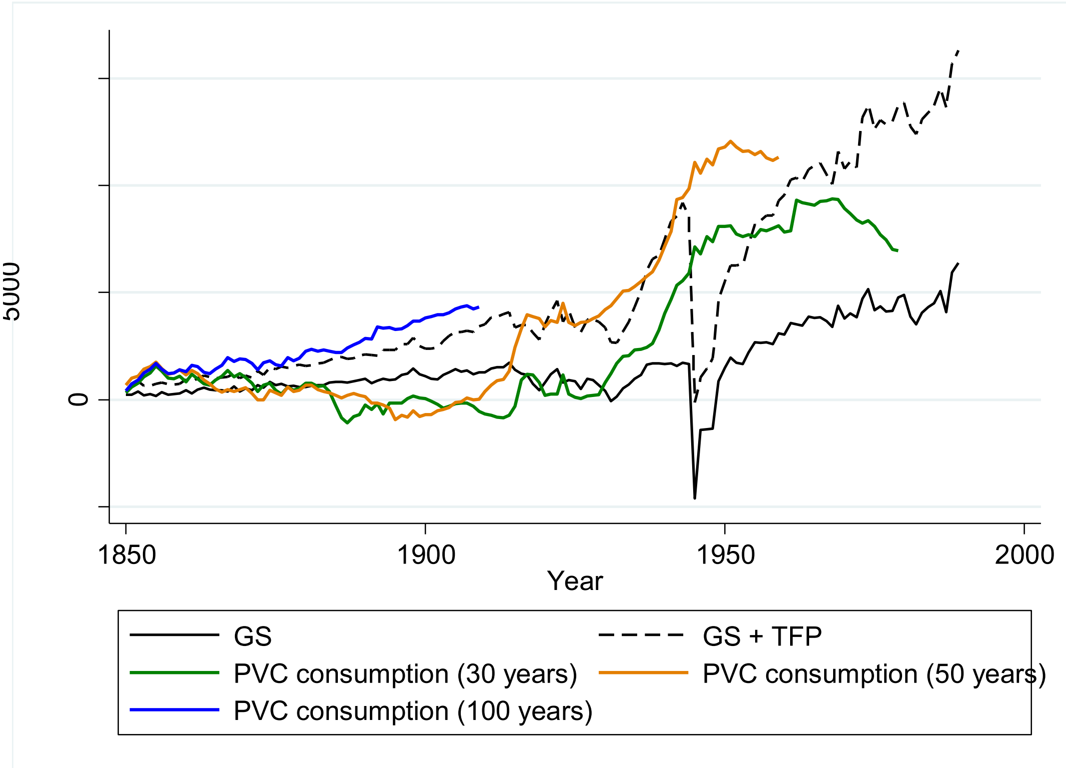


Figure 4: Infant Mortality Rate and Genuine Savings in Germany, 1850-2000

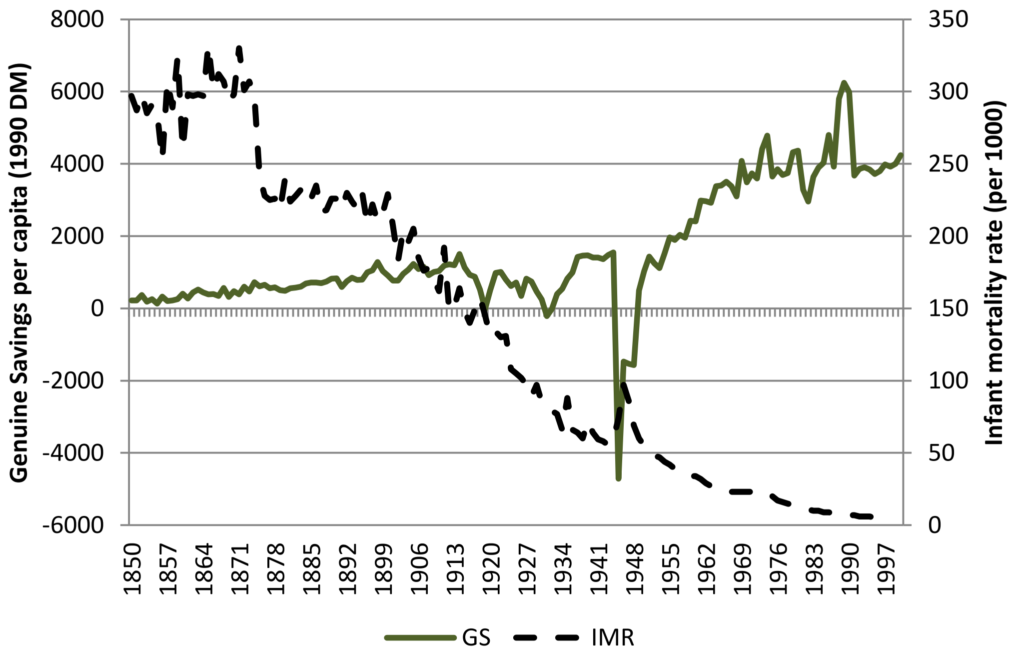


Figure 5: Average height (in cm) in Germany and Genuine savings per capita, 1850-2000

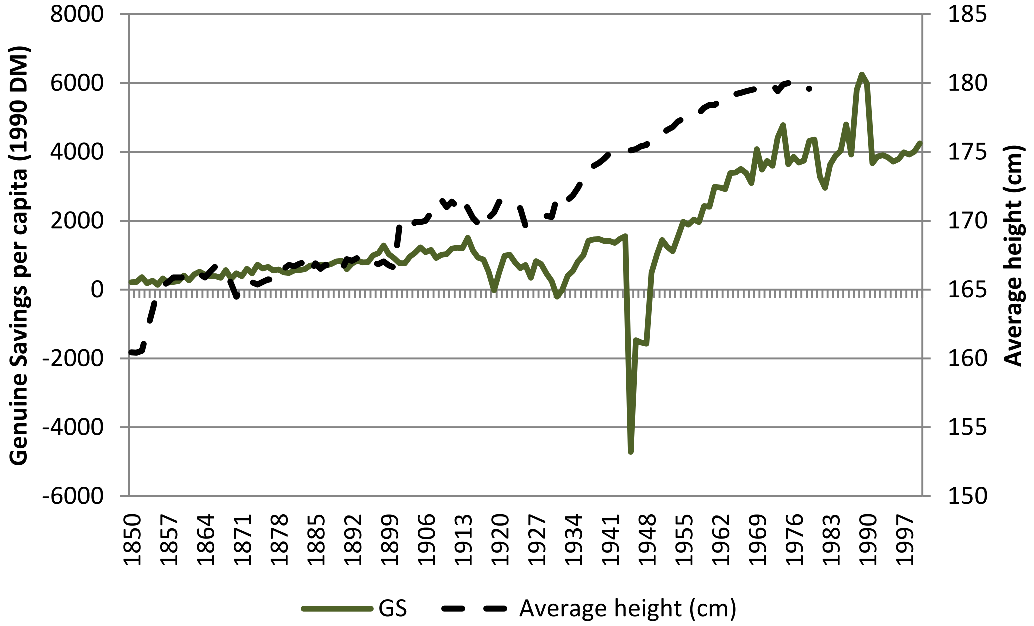


Figure 6a: Net, Green and GS in Germany, 1850-2000

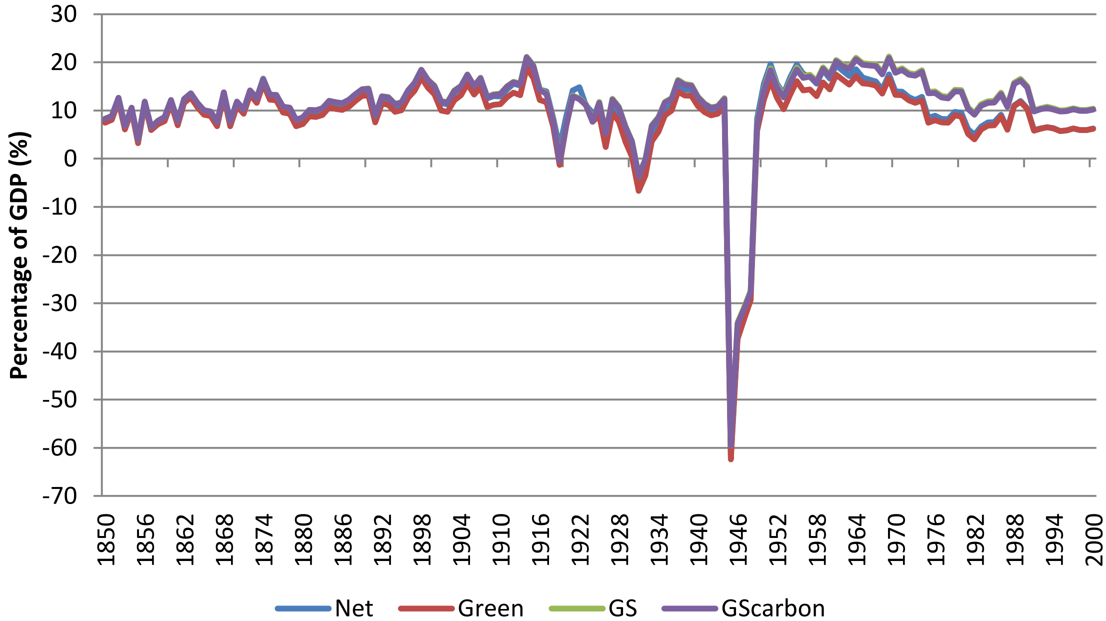


Figure 6b Genuine Savings per capita (with and without the present value of changes in TFP) 1851-2000

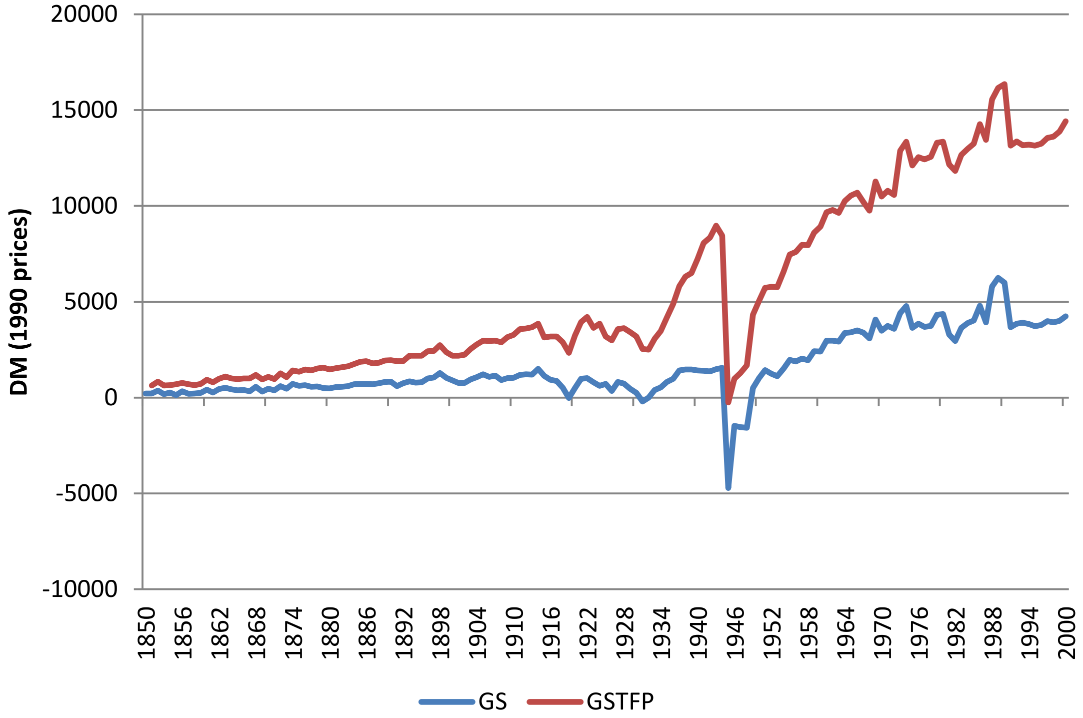


Figure 7a: Investment and future consumption over 50 years (1.95% discount rate)

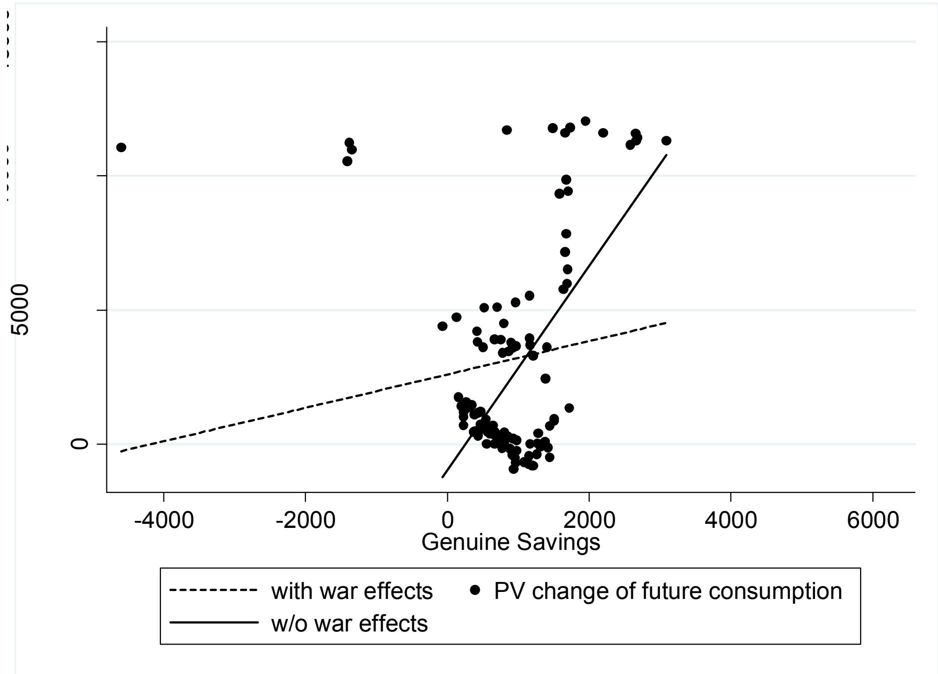


Figure 7b: Investment and changes in average height over 30 years

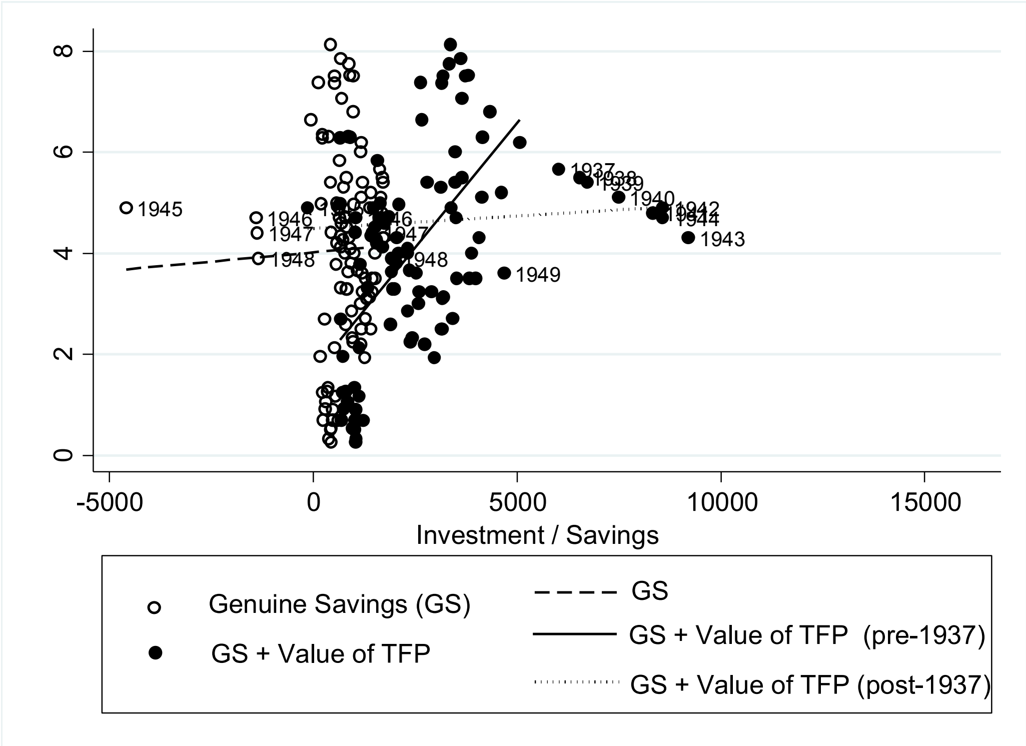
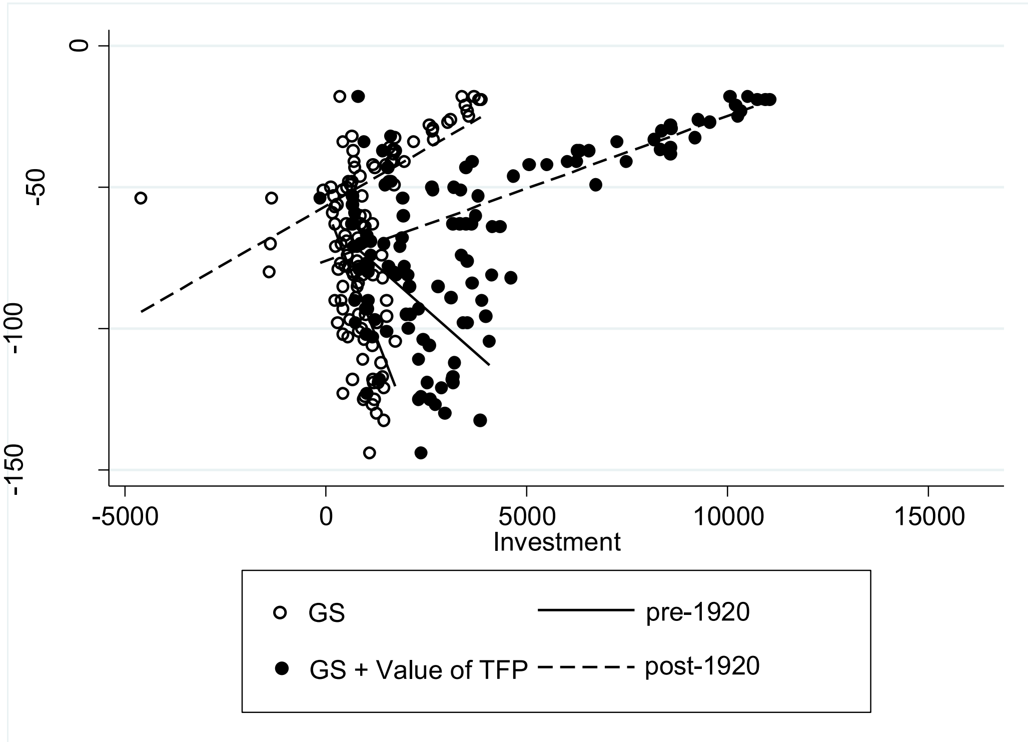


Figure 7c: Investment and changes in infant mortality over 30 years



Appendix 1 Robustness tests: accounting for an alternative discount rates and territorial changes

As a first robustness check, we switch to an alternative discount rate of 3 per cent, which is based on real GDP growth of the German economy during the period under observation (table A1). For this scenario, we conclude again that the incorporation of present value of changes in future TFP improves the quality of the analysis. A comparison of values presented in Table A2 illustrates that investment metrics which do not incorporate TFP suffer from aforementioned distortion (for a comprehensive comparison see tables A1). Among the undistorted results of this set of regressions we also find a positive relationship ($\beta_1 > 0$) throughout all investments measures and time horizons. Here, empirical results are similar to the ones using a 1.95 per cent benchmark and also indicate the existence of a positive relationship between current investment and future utility ($\beta_1 > 0$). For unbiased estimates, we also find that $\beta_1 > 0$ and $\rightarrow 1$ when additional forms of investment are considered over all time horizons. The opposite is true when looking at well-being changes over 100 years ahead: the value of β_1 for conventional net investment is fairly close to the predicted value of 1; incorporating additional forms of investment leads to a divergence of this coefficient from the value 1. Adding technological change confirms $\beta_1 > 0$, but not $\beta_1 > 0$ and $\rightarrow 1$. In the 3 per cent scenario we also reject the hypothesis that $\beta_1 = 1$ & $\beta_0 = 0$. For cointegration tests, we find conventional investment series are equally cointegrated with the present value of future consumption over 100 years, indicating that there is no particular advantage of adjusted net saving indicators in this regard.

The evidence presented in tables 3 and 4, the results are sensitive to both time horizons and discount rates. We assess the role of discount rates in the prediction framework by expressing β1 coefficients, which are results of a set of regression models, as a function of a range of discount rates between 0.10 and 3 per cent. The variables affected by changing discount rates are the present value of future changes in consumption and also the present value of TFP. The results for the correlation between GS (incl. TFP) and the present value of future changes in consumption over 30, 50, and 100 year spans are shown in figure A1.[24] For lower discount rates, β1 coefficients tend to be larger whereas for high discount rates the opposite is true. Moreover, the longer the time span under observation the sharper is the response (decline) in terms of β1 coefficient to increasing discount rates. Of all our time spans, the 100 year period is most sensitive to changes in the discount rate with β1 coefficients ranging from 6.05 to 0.37.

We also use this mechanism to identify an 'optimal' discount rate that is necessary to obtain the β1 value of 1 that is implied by theory. For 30 years this is clearly impossible given that the starting levels are below 1. The 50 year horizon has a β1 coefficient equal to 1 at a discount rate of approximately 3 per cent; the corresponding intersection point of the 100 year horizon is approximately 2.24 per cent. These coefficients enable us to evaluate how suitable our chosen discount rate is in the German case. The 1.95 per cent rate in our preferred scenario is based on real returns to German government bonds, while the results of our calibration exercises, shown in figure 8, suggest 2.24 per cent for 100 years horizon which is in close proximity to the rate suggested by historical national accounts, and 3 per cent is close to a long-run GDP growth rate.

We run another robustness test, simulating the continuous existence over the period under observation of the former Western part of Germany as it existed between 1945 and 1989 in order to address the multiple territorial changes which occurred over the period. The most important territorial changes include the temporary annexation of Alsace-Lorraine (1871-

[24] Correlations between GS and the present value of future changes in consumption (incl. war years) show a similar story with the 100 year horizon most sensitive to choice of discount. At no point does the 50 year horizon have a β1 coefficient equal to 1.

1918), as well as territorial losses after 1918/19 and 1945. Moreover, the figures used in this compilation for the post-1945 period do not include the East German economy. Accordingly, most statistics fall short of covering an "unchanged" German territory, potentially biasing the results of our empirical tests. To find appropriate metrics to weight Germany's territories, we use Maddison (1995) who reports the economic power for the territories that formed former Germany. For example, in 1936, the territory which later forms 'West Germany' accounts for 64 per cent of total economic power at the time. The territory that becomes 'East Germany' accounts for approximately 25 per cent; the territories east to the Oder-Neisse line account for the remaining 11 per cent. In 1990, the Western part of the re-united Germany accounts for approximately 90 per cent of the total figure. These weights are used to construct estimates of GDP, net investment, private consumption and pollution series for West Germany. We use Maddison's (1995) per-capital figures and census population figures provided by the Statistical Office of the German Empire (1910) to estimate the economic weight of the territories lost after WWI.

For resource extraction, figures are available allowing detailed adjustments even for smaller territorial units. Most significantly, territories east to the Oder-Neisse line accounted for approximately half of the hard coal extraction before WWI, and East Germany accounted for approximately 70 per cent of overall German brown coal production, but only 3 per cent of hard coal production. Other minerals and energy sources account for very little compared to hard and brown coal production. Accordingly, we subtract 70 per cent of brown coal production for the pre-1945 period, 3 per cent and 50 per cent of hard coal production for pre-1945 and pre-1918 period, respectively, to obtain a continuous West Germany series. For education expenditure, given the similar institutional standards we assume that per-capita expenditure was fairly similar throughout Germany. Therefore, we use shares of population in respective territories to identify education expenditures in West Germany. Territories ceded to Poland after WWI – other territories constitute a negligible share – account for approximately 4.4 per cent of Germany's population. East Germany and the territories annexed by Poland and the Soviet Union after WWII accounted for approximately 37 per cent of pre-war population (Maddison 1995, German census 1910). We adjust education expenditure using these population shares to obtain hypothetical West German data series. The result of this exercise confirms earlier results. Results are almost identical, irrespective whether the analysis is based on actual German figures, or on hypothetical West German ones (see Table A2).

Table A1: Estimated parameter values for alternative measures of investment when future wellbeing is measured by the PV of consumption per capita over 20-100 years horizons, 3 per cent /year discount rate

Dependent variable	Independent variable	β1	Standard error	β0	Standard error	N	β1=1	β0=0; & β1=1	ADF	R^2	Sample
PV Cons. 30	Net	1.427***	(0.219)	937.9***	(315.9)	130	3.81*	19.07***	-1.723	0.25	1850-1979
PV Cons. 50		0.0601	(0.379)	2,353***	(395.5)	110	6.16**	19.12***	0.442	0	1850-1959
PV Cons. 100		0.839***	(0.124)	705.3***	(82.48)	60	1.67	154.27***	-2.970**	0.44	1850-1909
PV Cons. 30	Green	1.393***	(0.235)	1,125***	(313.2)	130	2.80*	20.59***	-1.611	0.216	1850-1979
PV Cons. 50		-0.23	(0.396)	2,525***	(379.6)	110	9.63**	22.68***	1.533	0.003	1850-1959
PV Cons. 100		0.894***	(0.144)	715.9***	(87.21)	60	0.55	167.34***	-2.877**	0.401	1850-1909
PV Cons. 30	GS	1.320***	(0.172)	840.9***	(295)	130	3.47*	16.55***	-1.753	0.316	1850-1979
PV Cons. 50		0.0596	(0.384)	2,352***	(404.9)	110	6.00**	18.51***	0.545	0	1850-1959
PV Cons. 100		0.815***	(0.122)	701.6***	(83.53)	60	2.31	142.57***	-2.968**	0.437	1850-1909
PV Cons. 30	GScarbon	1.325***	(0.176)	859.9***	(296.6)	130	3.43*	16.82***	-1.744	0.308	1850-1979
PV Cons. 50		0.0155	(0.386)	2,383***	(403.6)	110	6.50**	18.93***	1.354	0	1850-1959
PV Cons. 100		0.819***	(0.123)	701.5***	(83.94)	60	2.18	143.20***	-2.959**	0.434	1850-1909
PV Cons. 30	GreenTFP	0.793***	(0.0544)	-546.3**	(258.2)	129	14.47***	38.63***	-2.424	0.626	1851-1979
PV Cons. 50		1.079***	(0.122)	-413.3	(394.7)	109	0.43	0.60	-2.299	0.424	1851-1959
PV Cons. 100		0.395***	(0.0483)	653.5***	(76.23)	59	157.29***	105.99***	-3.307**	0.54	1851-1909
PV Cons. 30	GSTFP	0.715***	(0.0492)	-451.5*	(253.7)	129	33.51***	62.07***	-2.200	0.625	1851-1979
PV Cons. 50		1.052***	(0.117)	-470.9	(395.2)	109	0.20	1.10	-2.289	0.431	1851-1959
PV Cons. 100		0.372***	(0.0452)	659.8***	(75.12)	59	192.95***	144.52***	-3.314**	0.543	1851-1909

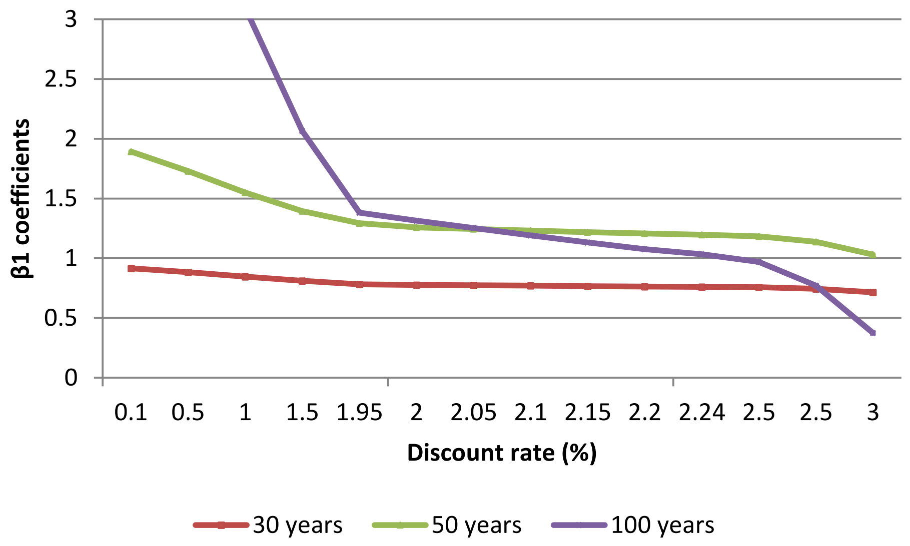
Note: Discount rate of 3 per cent per anno was chosen on the basis of average real growth rate of the German economy during the period under observation. Also see table 1 for notes. See also table 1.

Table A2: Alternative discount rates, 1.95% and 3%, Germany and West Germany

		(1)	(2)	(3)	(4)
		Germany	Germany	West Germany	West Germany
		1.95%	3%	1.95%	3%
PV Cons. 30	Net	1.636***	1.427***	1.163***	1.040***
PV Cons. 50		0.063	0.0601	-0.179	-0.137
PV Cons. 100		3.356***	0.839***	3.925***	1.265***
PV Cons. 30	Green	1.596***	1.393***	-1.216***	-1.088***
PV Cons. 50		-0.301	-0.23	0.183	0.125
PV Cons. 100		3.629***	0.894***	-4.184***	-1.339***
PV Cons. 30	GS	1.515***	1.320***	-0.844**	-0.769***
PV Cons. 50		0.0774	0.0596	0.495	0.366
PV Cons. 100		3.279***	0.815***	-4.656***	-1.476***
PV Cons. 30	GScarbon	1.520***	1.325***	-1.086***	-0.978***
PV Cons. 50		0.0217	0.0155	0.231	0.155
PV Cons. 100		3.298***	0.819***	-4.520***	-1.442***
PV Cons. 30	GreenTFP	0.861***	0.793***	1.474***	1.382***
PV Cons. 50		1.327***	1.079***	2.048***	1.719***
PV Cons. 100		1.460***	0.395***	3.635***	1.447***
PV Cons. 30	GSTFP	0.781***	0.715***	0.814***	0.749***
PV Cons. 50		1.294***	1.052***	1.568***	1.299***
PV Cons. 100		1.380***	0.372***	1.584***	0.551***

Note: Please see tables 3 and 4 for additional information on these empirical tests.

Figure A1: β1 coefficients by time horizon as a function of the discount rate applied



Appendix 2: Data appendix

Table 1a: Descriptive statistics (refer to results presented in table 2):

	N	Mean	Median	Standard Deviation	Minimum	Maximum
Net investment	151	1209.17	961.84	1171.45	-4883.35	4527.06
Green	151	1100.75	847.24	1136.14	-4940.30	4456.82
Genuine Savings (GS)	151	1559.38	990.55	1628.96	-4713.19	6245.64
GS carbon	151	1529.91	975.93	1596.84	-4717.17	6133.14
GS TFP	150	5551.64	3253.44	4694.88	-256.09	16352.83
Green TFP	150	5090.10	3151.64	4139.48	-483.19	14473.07
PVC 30 years	130	2735.24	983.69	3511.25	-1073.66	9360.81
PVC 50 years	110	3141.31	1179.44	4033.04	-944.89	12046.91
PVC 100 years	60	2375.34	2085.09	1070.67	421.86	4381.07

Note: All investment measures are corrected for population changes; consumption: present value of future private consumption.

Data sources

GDP and GDP deflator: Pre-1975 data on German national product is available from Flora et al. (1983) and Hoffmann et al. (1965). GDP levels for later periods are taken from German Statistical Yearbooks (1999, 2008). Missing periods 1914-1924 and 1940-1949 were estimated using Ritschl and Spoerer's (1997) GNP series. A GDP deflator was constructed using data from Hoffman et al. (1965), Mitchell (2007) and the United Nations Statistical Division (2013).

Net investment: Net investment from 1850-1959 is provided by Hoffmann et al. (1965). We estimated the gap during 1914-1924 using Kirner (1968) who reports investment in buildings, construction, and equipment by sector for the war and inter-war periods. The period 1939 to 1949 was estimated by using data on net capital stock provided by Krengel (1958).[25] To

[25] Despite the existence of several estimates and approximations of the development of investment we stick to Krengel's (1958) data (Vonyó 2012, Scherner 2013).

estimate investment during 1960 to 1975 we used Flora et al.'s (1983) data on net capital formation. For the period 1976 to 2000 we use official World Bank (2010) and United Nations (2013) investment statistics to complete the series. Data on the change in overseas capital stock and advances is provided by Hoffmann et al. (1965). Gaps during war and inter-war periods were estimated using information on the balance of payments provided by the German central bank (DeutscheBundesbank, 1998, 2005). Remaining missing values were estimated using trade balances as a proxy for capital flows (DeutscheBundesbank, 1976; Flora et al., 1983; Hardach, 1973).

Private Consumption is taken from Flora et al. (1983), German Statistical Office, downloadable under www.gesis.oreg/histat (Bundesamt, 2013), Ritschl (2005), Abelshauser (1998), and Harrison (1988).

Average height data are taken from the following sources: Germany (West und total): Jaeger et al. (2001), Komlos and Kriwy (2003); Germany (East): Jaeger et al. (2001), Komlos and Kriwy (2003); Bavaria: Baten (1999), Baten and Murray (2000), Harbeck (1960); Württemberg: Twarog (1997); Palatinate: Baten (1999), Baten and Murray (2000); Northrhine-Westphalia: Blum (2011); (Blum, 2012). Average height is organized by birth date, reflecting socioeconomic conditions around birth since this is the most important period for the determination of final average adult height.

Data in **infant mortality rates** are provided by Mitchell (2007) and measures the share number of infants (by 1000) who died within the first 12 months after birth.

Forestry: Germany had an established reputation as one of the most advanced nations involved in forestry management and inspired British and U.S. developments in silviculture (e.g. see Schlich (1904), Zon (1910), Hiley (1930), B.P.P. (1942-43), Heske (1938)). Information on German forestry stock was taken from Zon (1910), Zon et al. (1923), Hoffmann et al. (1965), and Endres (1922).

Non-renewable resources: Fischer (1989) and Fischer and Fehrenbach (1995) provide detailed data on German mining activities including the number of employees in mining, covering the period until the 1970s. Information on quantities and market prices by commodity on an annual basis are available. Additional information was collected from Mitchell (2007). Data provided by Fischer (1989) and Fischer and Fehrenbach (1995) are also available by German state, which allows subtracting contemporary contributions of the mining sector of Alsace-Lorraine between 1871 and 1918. Moreover, the statistical offices of the German Empire and the Federal Republic of Germany provide information on the 1914 to 1923 as well as the post-1962 periods, respectively (Bundesamt, 2013; Germany. Statistisches Reichsamt., 1925).

To assess the costs of depletion the number of employees in mining and their average wage were used. Data on the labour force in mining is provided by Fischer (1989), Fischer and Fehrenbach (1995), and the German Statistical Office (2013). Wages of mining workers are reported by Hoffmann et al. (1965), Kuczynski (1947), Mitchell (2007), and official contemporary statistics (Germany. Statistisches Reichsamt., 1925).

Expenditure on schooling: Data on education expenditure is provided by Hoffmann et al. (1965) and Diebolt (1997, 2000). For the post-1990 period we use World Bank data on education expenditure. Missing values for the periods 1922-24 and 1938-48 have to be estimated. For the former period, we assume that expenditures between 1921 and 1925 developed gradually and apply linear interpolation. For the latter period we use Flora (#, p. 585) who reports that the number of pupils and students in Germany dropped by 16.3 per cent between 1936 and 1950 – this occurred most likely due to population losses after WWII. The corresponding drop in education expenditure was 16.5 per cent. We assume that the 1939 expenditure level was maintained until 1945, when the number of students plummeted. Therefore, we assume that the expenditure level between 1946 and 1948 was equal to the 1949 figure.

Carbon emissions: German carbon pollution estimates were taken from Andres et al. (1999) and Boden et al. (1995).

TFP: Data on labour hours worked and real GDP is taken from Greasley and Madsen (2006). Information on capital stock for the period 1850 through 2000 is provided by Metz (2005). Missing values during and after WW2 have been estimated on the basis of Krengel (1958). Factor shares used were from Greasley and Madsen (2006), capital share is 0.60 and labour 0.40. A Kalman filter of the TFP growth rate was estimated.

Discount rates: Data on historical interest rates and government bond yields were taken from Homer and Sylla (2005) and Deutsche Bundesbank (2013)[26].

[26] Data download from http://www.bundesbank.de, accessed 23/9/2013